Valuing Agroforestry Systems

Advances in Agroforestry

Volume 2

Series Editor:

P.K.R. Nair

School of Forest Resources and Conservation,
University of Florida, Gainesville, Florida, U.S.A.

Aims and Scope

Agroforestry, the purposeful growing of trees and crops in interacting combinations, began to attain prominence in the late 1970s, when the international scientific community embraced its potentials in the tropics and recognized it as a practice in search of science. During the 1990s, the relevance of agroforestry for solving problems related to deterioration of family farms, increased soil erosion, surface and ground water pollution, and decreased biodiversity was recognized in the industrialized nations too. Thus, agroforestry is now receiving increasing attention as a sustainable land-management option the world over because of its ecological, economic, and social attributes. Consequently, the knowledge-base of agroforestry is being expanded at a rapid rate as illustrated by the increasing number and quality of scientific publications of various forms on different aspects of agroforestry.

Making full and efficient use of this upsurge in scientific agroforestry is both a challenge and an opportunity to the agroforestry scientific community. In order to help prepare themselves better for facing the challenge and seizing the opportunity, agoroforestry scientists need access to synthesized information on multi-dimensional aspects of scientific agroforesty.

The aim of this new book-series, *Advances in Agroforestry*, is to offer state-of-the art synthesis of research results and evaluations relating to different aspects of agroforestry. Its scope is broad enough to encompass any and all aspects of agroforestry research and development. Contributions are welcome as well as solicited from competent authors on any aspect of agroforestry. Volumes in the series will consist of reference books, subject-specific monographs, peer-reviewed publications out of conferences, comprehensive evaluations of specific projects, and other book-length compilations of scientific and professional merit and relevance to the science and practice of agroforestry worldwide.

Valuing Agroforestry Systems

Methods and Applications

by

JANAKI R.R. ALAVALAPATI

School of Forest Resources and Conservation,
University of Florida, Gainesville, Florida, U.S.A.

and

D. EVAN MERCER

U.S. Forest Service,
Southern Research Station,
Research Triangle Park, North Carolina, U.S.A.

KLUWER ACADEMIC PUBLISHERS

NEW YORK, BOSTON, DORDRECHT, LONDON, MOSCOW

eBook ISBN: 1-4020-2413-4
Print ISBN: 1-4020-2412-6

TABLE OF CONTENTS

CONTRIBUTORS

Janaki R.R. Alavalapati
School of Forest Resources and Conservation, University of Florida, Gainesville, Florida, United States.

Peter Blandon
Department of Business Studies, London Metropolitan University, London, United Kingdom.

Geoff Bright
School of Agricultural and Forest Sciences, University of Wales, Bangor, United Kingdom.

Oscar Cacho
School of Economics, University of New England, Armidale, Australia.
Cooperative Research Centre for Plant-based Management of Dryland Salinity.

Ben H. J. De Jong
El Colegio de la Frontera Sur, Unidad Villahermosa, Villahermosa, Tabasco, México.

Brooks M. Depro
RTI International, Research Triangle Park, North Carolina, United States.

W. Mark Drew
School of Forest Resources and Conservation, University of Florida, Gainesville, Florida, United States.

Elsa Esquivel-Bazán
Ambio, San Cristóbal de las Casas, Chiapas, México.

Steven Franzel
World Agroforestry Centre (ICRAF), Nairobi, Kenya.

Stephen C. Grado
Department of Forestry, College of Forest Resources, Mississippi State University, Mississippi, United States.

Robyn Hean
Agroforestry Unit, New South Wales Agriculture, Tamworth, Australia.
Cooperative Research Centre for Plant-based Management of Dryland Salinity.

Peter E. Hildebrand
Department of Food and Resource Economics, University of Florida, Gainesville, Florida, United States.

Amanda L. Husak
Department of Forestry, College of Forest Resources, Mississippi State University, Mississippi, United States.

Shashi Kant
Faculty of Forestry, University of Toronto, Ontario, Canada.

Emma Lehrer
Faculty of Forestry, University of Toronto, Ontario, Canada.

D. Evan Mercer
United States Department of Agriculture – Forest Service, Southern Research Station, Research Triangle Park, North Carolina, United States.

Jensen R. Montambault
School of Natural Resources and Environment, University of Florida, Gainesville, Florida, United States.

Maxwell Mudhara
Department of Agricultural Economics and Extension, University of Zimbabwe, Harare, Zimbabwe.

P. K. R. Nair
School of Forest Resources and Conservation, University of Florida, Gainesville, Florida, United States.

Susana Ochoa-Gaona
El Colegio de la Frontera Sur, Unidad Villahermosa, Villahermosa, Tabasco, México.

Nicolás Peréz-Hernández
Ambio, San Cristóbal de las Casas, Chiapas, México.

Subhrendu K. Pattanayak
RTI International, Research Triangle Park, North Carolina, United States.
North Carolina State University, Raleigh, North Carolina, United States.

Sotero Quechulpa-Montalvo
Ambio, San Cristóbal de las Casas, Chiapas, México.

Ram K. Shrestha
School of Forest Resources and Conservation, University of Florida, Gainesville, Florida.

Ann Snook
Universidad de Quintana Roo, Chetumal, Quitana Roo, Mexico.

Paul H. Thangata
World Agroforestry Centre (ICRAF), Southern Africa Regional Programme, Harare, Zimbabwe.

Runsheng Yin
Department of Forestry, Michigan State University, East Lansing, Michigan, United States.

PREFACE

The primary objective of this book is to offer practical means for strengthening the economics and policy dimension of the agroforestry discipline. This book, written by the leading experts in economics and agroforestry, encompasses case studies from Australia, China, Kenya, India, Indonesia, Malawi, Mexico, Micronesia, Tanzania, United Kingdom, United States, Zambia, and Zimbabwe. The applied economic methodologies encompass a wide variety of case studies including enterprise/farm budget models through Faustmann models, Policy Analysis Matrix, production function approach, risk assessment models, dynamic programming, linear programming, meta-modeling, contingent valuation, attribute-based choice experiments, econometric modeling, and institutional economic analysis. It is our belief that these methodologies help agroforestry students and professionals conduct rigorous assessment of economic and policy aspects of agroforestry systems and to produce less biased and more credible information.

Furthermore, the economic and policy issues explored in the book – profitability, environmental benefits, risk reduction, household constraints, rural development, and institutional arrangements – are central to further agroforestry adoption in both tropical and temperate regions.

All of the chapters in this volume were subject to rigorous peer review by at least one other contributing author and one external reviewer. We would like to acknowledge the indispensable collaboration of those who provided careful external reviews: Ken Andrasko, Chris Andrew, Peter Boxall, Norman Breuer, Bill Hyde, Tom Holmes, Sherry Larkin, Jagannadharao Matta, Venkatrao Nagubadi, Roz Naylor, Thomas Randolph, Gerald Shively, Changyou Sun, Bo Jellesmark Thorsen, and Yaoqi Zhang. All reviews were coordinated by the book editors.

We would like to take this opportunity to express our gratitude to all the authors and co-authors of each chapter for their valuable contribution and timely response. Special thanks are extended to Jensen Montambault for making the production of this volume on a tight time schedule possible through editing, technical, and formatting assistance. We are also grateful for additional formatting and indexing assistance supplied by Terri Mashour, Troy Timko, and Fauzia Zamir. Generous in-kind and direct support were provided by the University of Florida and the USDA Forest Service. Finally, we would like to express our appreciation for the guidance of the editors at Kluwer Academic Publishing, Helen Buitenkamp, Sandra Oomkes, and Amber Tanghe-Neely.

– The Editors

JANAKI R. R. ALAVALAPATI, D. EVAN MERCER, AND
JENSEN R. MONTAMBAULT

AGROFORESTRY SYSTEMS AND VALUATION METHODOLOGIES

An Overview

1. INTRODUCTION

Agroforestry, the deliberate integration of trees with agricultural crops and/or livestock either simultaneously or sequentially on the same unit of land, has been an established practice for centuries. Throughout the tropics and, to some extent, temperate zones, farmers have a long tradition of retaining trees on their fields and pastures, as well as growing crops or raising domestic animals in tree stands or forests (Alavalapati & Nair, 2001; Gordon & Newman, 1997; Nair, 1989). In the late 1970s, agroforestry attracted the attention of the international scientific and development communities due to its potential for improving the environment and livelihood of rural tropical communities. The agroforestry prospective increased further during the 1990s as scientists and policy makers recognized the potential for applying agroforestry systems (AFS) to problems such as soil erosion, rising salinity, surface and ground water pollution, increasing greenhouse gases, and biodiversity losses in temperate zones and developed economies. Financial viability and attractiveness has also proven AFS an important land use alternative in various settings throughout the world (Garrett, 1997), generating increased interest in this sustainable land-use management practice with potential environmental and socioeconomic benefits.

Research over the past two decades has focused on exploring the biophysical and ecological aspects of agroforestry with a limited emphasis on social aspects of agroforestry, especially economics, policy analysis, and valuation of associated environmental services (Mercer & Miller, 1998). Concern over adoption rates has highlighted the importance of integrating socioeconomic elements into traditional biophysical agroforestry research (Nair, 1998; Rochelau, 1998). As a result, there is a growing interest and need for enhancing economic and policy research among

J. R. R. Alavalapati & D. E. Mercer (Eds.), Valuing Agroforestry Systems, 1–8.

agroforestry professionals. Montambault and Alavalapati (2003) conducted an extensive review and analysis of socioeconomic research in agroforestry literature between 1992 and 2002. Results showed a clear increasing trend in publications with more complex analyses, such as econometrics and optimization. The development of more sophisticated economic models creates applications that give more realistic and useful results for agroforestry practitioners. Indeed, the first World Agroforestry Congress (June 2004, Orlando, Florida) identified economics and policy as one of the key areas for enhancing the impacts of agroforestry. As an emerging facet of an interdisciplinary science, no single reference book prior to this publication has provided adequate coverage of applied economic and policy analysis methodologies for agroforestry professionals. By addressing this need, the present text offers practical means for strengthening the economics and policy elements of the agroforestry discipline.

2. DIVERSE AGROFORESTRY SYSTEMS AND ECONOMIC METHODOLOIGIES

Small-scale AFS range from slash-and-burn and taungya systems to traditional, yet complex, homegardens. More recent innovations include alley cropping and improved fallows and have been expanded to larger-scale production. As shown in Tables 1A and 1B, the nature, complexity, and objectives of AFS vary greatly between the tropics and the temperate zone.

Table 1A. Major agroforestry practices in tropical systems.

Agroforestry practice	*Brief description*
Taungya	Agricultural crops grown during the early stages of forest plantation establishment.
Homegardens	Intimate, multistory combinations of a variety of trees and crops in homestead gardens; livestock may or may not be present.
Improved fallow	Fast-growing, preferably leguminous woody species planted during the fallow phase of shifting cultivation; the woody species improve soil fertility and may yield economic products.
Multipurpose trees	Fruit and other trees randomly or systematically planted in cropland or pasture for the purpose of providing fruit, fuelwood, fodder, and timber, among other services, on farms and rangelands.
Plantation-crop combinations	Integrated multistory mixtures of tree crops (such as coconut, cacao, coffee, and rubber), shade trees, and/or herbaceous crops.
Silvopasture	Combining trees with forage and livestock production, such as grazing in existing forests; using trees to create live fences around pasture; or to provide shade and erosion control.

(Table 1A, cont.)

Agroforestry practice	*Brief description*
Shelterbelts and windbreaks	Rows of trees around farms and fields planted and managed as part of crop or livestock operations to protect crops, animals, and soil from natural hazards including wind, excessive rain, seawater, or floods.
Alley cropping	Fast-growing, preferably leguminous woody species in single or grouped rows in agricultural fields. Prunings from the woody species are applied as mulch into the agricultural production alleys to increase organic matter and nutrients and/or are removed from the field for other purposes such as animal fodder.

Table 1B. Major agroforestry practices in temperate systems.

Agroforestry practice	*Brief description*
Alley cropping	Trees planted in single or grouped rows within agricultural or horticultural fields with crops grown in the wide alleys between the tree rows.
Forest farming	Forested areas used for production or harvest of natural standing specialty crops for medicinal, ornamental, or culinary uses (e.g., ginseng, ferns, shiitake mushrooms).
Riparian buffer strips	Strips of perennial vegetation (tree/shrub/grass) planted between croplands/pastures and water sources such as streams, lakes, wetlands, and ponds to protect water quality.
Silvopasture	Combining tress with forage and livestock production, such as: growing trees on ranchlands; grazing in existing forests; providing shade and erosion control or environmental services.
Shelterbelts and Windbreaks	Rows of trees around farms and fields planted and managed as part of crop or livestock operations to protect crops, animals, and soil from natural hazards including wind, excessive rain, seawater, or floods.

Sources for Tables 1A, 1B: Association for Temperate Agroforestry [AFTA], 1997; Alavalapati & Nair, 2001; Nair, 1994.

A variety of economic and policy issues such as profitability, household benefits, equity, sustainability, soil conservation, environmental services, markets for inputs and outputs, gender, and institutions (property rights, for example) influence the nature and magnitude of AFS adoption (Alavalapati & Nair, 2001; Mercer & Hyde, 1991). A range of economic methodologies is required to systematically investigate these issues and produce objective and unbiased information to assist land managers and policy makers with AFS related decision-making.

Economic methodologies help characterize the mental calculus of a decision maker, whether a private landowner or a policy maker. As such, these models can be viewed as abstract representations of the real world useful for hypothesis generation, forecasting, policy analysis, and decision-making (Buongiorno & Gilles, 2003). These methodologies are diverse in terms of their focus, scale (temporal and spatial), and scope (Table 2). Some economic methodologies are designed to assess simple cost and benefits of outputs and inputs for which markets are fairly established while others may be limited only by scientists' capabilities and imagination. Methodologies are also available for assessing a variety of environmental advantages and challenges (e.g., carbon sequestration, biodiversity, and soil erosion) for which there are no established markets. While some methodologies are appropriate for assessing AFS at the individual farm or household level, others are applicable at regional and national scales. Partial equilibrium models are used to assess impacts on particular economic sectors by assuming that changes in AFS only affect certain sectors of the economy. Broader impacts can be analyzed with general equilibrium models that include intersectoral linkages capturing the multiplier and/or trade impacts of changes in AFS on other sectors of the economy. Although these models and methods have been extensively applied in agricultural and forest economics literature, AFS applications are relatively rare.

Table 2. Economic methodologies common in agricultural and/or forest economics literature.

Economic methodology	*Brief description*
Enterprise/farm budget models	Estimate the profitability of a farm or enterprise by deriving indicators such as net present values (NPV), benefit-cost ratio (BCR), and internal rate of return (IRR).
Policy analysis matrix models (PAM)	Similar to farm budget models, but also include market failures, assessing their impact on profitability at a farm or regional level from both the individual and society perspectives.
Risk assessment models	Incorporate probabilities of events occurring and estimate the expected profitability of AFS enterprises.
Dynamic optimization models	Estimate optimum values (e.g., timber rotation age and tree cover) under limited, terminating time periods or perpetual scenarios.
Liner and non-linear programming models	Estimate optimum resources use/allocation subject to various constraints faced by the decision maker.
Econometric models	Estimate the relationships among variables under investigation for forecasting, policy analysis, and decision-making.
Non-market valuation models	Hedonic and contingent valuation models, for example, estimate values for environmental goods and services such as reducing soil erosion, improving water quality, and carbon sequestration.
Regional economic models	Generally used to estimate changes in income, employment, and price levels at regional or national scales, in response to a policy or programmatic change by incorporating intersectoral linkages.

As each methodology has its own strengths and weaknesses, it would be erroneous to base conclusions on the scope, scale, or complexity of the models. Model choice depends primarily upon the nature of the research problem, data availability, and the skills and training of the analyst. A state-of-the-art Computable General Equilibrium (CGE) approach (Das & Alavalapati, 2003), for example, may be inappropriate and not very useful for assessing the profitability of an improved fallow system from a private landowner's perspective. This book, written by the leading experts in the field, encompasses 16 chapters arranged under 5 subsections and consists of 14 case studies covering all the continents of the world. The countries covered include Australia, China, Kenya, India, Indonesia, Malawi, Mexico, Micronesia, Tanzania, United Kingdom, United States, Zambia, and Zimbabwe. Each case study focuses on a specific type of economic methodology, illustrating its application to an AFS.

3. ORGANIZATION OF THE BOOK

One of the key factors influencing AFS adoption is its relative profitability compared with alternative land-use practices. Therefore, assessing the profitability of an AFS from a landowner perspective is of paramount importance. Chapters 2-6, in the second section, present a variety of methods for analyzing the profitability of AFS under different settings. In particular, Chapter 2 examines the profitability of fodder shrubs in Kenya, woodlots in Tanzania, and improved fallows in Zambia using an enterprise budget methodology. Chapter 3 extends the profitability analysis by applying a Land Expectation Value (LEV) approach (often referred to as the Faustmann methodology in the forest economics literature) using a silvopastoral system in the southern United States. This chapter estimates the present value of land under silvopasture system compared to alternative investment or management strategies. Chapter 4 is devoted to analyzing the private and social profitability of AFS in Pohnpei, Federated States of Micronesia using the Policy Analysis Matrix (PAM). In addition to quantifying profitability, the effect of distortions associated with policy or market failures (comparing private prices to social/efficiency prices) are assessed in this chapter. Chapter 5 develops a theoretical framework for analyzing the product-product relationship, the Production Possibility Frontier (PPF), and then applies the PPF to construct a simulation model of a wheat-maize-unpruned leucaena (*Leucaena leucocephala)* system in the Himalayan foothills of India. The model takes diminishing returns, time and interest, tree growth over time, complementarities and extra competition into account in assessing economic productivity. Chapter 6 analyzes risk in AFS through a portfolio approach applied to British and other European silvopasture practices, showing how AFS can help reduce risk and stabilize farmers' income.

As mentioned previously, AFS provide a mix of market goods such as food, wood products, and fodder, and non-market goods and services including soil conservation, water and air quality improvement, biodiversity conservation, and scenic beauty (Alavalapati, Shrestha, & Stainback, in press; Shrestha & Alavalapati, in press). The exclusion or inclusion of non-market goods and services, often referred to as externalities, largely differentiates private and social profitability. The third section of this book (Chapters 7-10) offers several environmental economic methodologies to value both market and non-market benefits of AFS. Chapter 7 examines the cost of carbon mitigation by means of agroforestry systems using a case study of farmers' participating in the Scolel Té project, Chiapas, Mexico. The methodology includes fixed and variable costs of implementing new AFS and the opportunity cost to farmers of diverting land from current land use, in addition to the cost of monitoring and internal verification of project performance. Chapter 8 deals with the estimation of external costs of dryland salinity emergence and the environmental and monetary benefits of tree planting in Australia. Using a dynamic programming model, the optimal area for forest on agricultural land is determined by explicitly considering the interactions between trees and crops. Chapter 9 assesses key environmental services such as conservation of on-farm soils and reduction of pressure on public forests through the adoption of AFS. Household production theory is used to conceptualize environmental services and policy levers and to frame testable hypotheses. Drawing from household survey data on agroforestry-based soil and forest conservation in the Manggarai region in Indonesia, the authors use an econometric model to test the hypotheses concerning soil erosion and AFS. Chapter 10 models an important externality problem, Florida ranchers' willingness to accept (WTA) for adopting silvopasture and generating environmental services, using a dichotomous choice, contingent valuation approach. In this chapter, a price premium is used as a payment vehicle to reflect the environmental services generated through silvopasture.

Since the mid-1990s, agroforestry adoption research has increased, largely motivated by perceived discrepancy between advances in agroforestry science and low adoption rates. The fourth section (Chapters 11-13) is devoted to the issue of AFS adoption and the myriad of factors influencing the adoption decision. Using a five-year linear programming (LP) model, Chapter 11 conducts an economic assessment of household constraints to the adoption of improved fallows in Mangwende Communal Area, northeastern Zimbabwe. Chapter 12 extends the previous model by conducting a meta-analysis of factors determining agroforestry adoption and farmers' decision-making in Malawi. In this chapter, information produced from LP models is used as the basis for conducting meta-regression analyses. Chapter 13 provides another perspective by describing an alternative econometric-based method for *ex-ante* analysis of AFS adoption potential. In particular, an attribute-based choice experiment (ACE), a subset of conjoint analysis, is applied to develop information for improving the adoption potential of agroforestry projects in southeast Mexico.

Although information generated through microeconomic analyses, profitability analysis and environmental economic analysis is essential for making agroforestry adoption decisions, information about the effect of AFS on regional income and employment plays a critical role in policy making. The fifth section (Chapters 14-15) focuses on the role of AFS in rural development and institutional arrangements required to further AFS adoption. Chapter 14 assesses the economic effects of agroforestry development in Northern China. Using state-of-the-art econometric time series techniques, the effect of agroforestry on agricultural productivity, and the spatial and temporal relationships between trees and annual crops are estimated. Chapter 15 provides an institutional economics perspective of AFS. In particular, the framework presented in this chapter provides an analytical approach to institutional analysis of agroforestry systems. The framework is applied to analyze market institutions as well as non-market institutions such as land tenure, tree-harvesting rights, transportation rights, tree-processing rights, loan arrangements, and technical support systems relating to Indian agroforestry.

Finally, Chapter 16 summarizes the main results and discusses the status of economic research and modeling in agroforestry. Drawing on the issues addressed in the book, gaps are identified as opportunities for further research in economic and policy of agroforestry.

4. SUMMARY

This book presents technical discussions of various AFS, economic theories, and methodologies applied to assess these systems in order to provide insight for policy and management. In doing so, the book covers 13 countries from all five continents of the world. Although the results presented in each chapter are based on specific case study data, they can be applied broadly because they are derived through appropriate rigorous quantitative approaches. This volume is primarily intended for upper division undergraduate and graduate students, as well as agroforestry and rural development professionals across the world. In addition, this book can be a significant new reference tool for resource economists, rural sociologists, and other social scientists interested in rigorous, quantitative analysis of agroforestry systems. Finally, this text is intended to provide valuable insights for policy makers and representatives of government and non-government agencies dealing with agroforestry practices in both developing and developed countries.

5. REFERENCES

Alavalapati, J. R. R., & Nair, P. K. R. (2001). Socioeconomics and institutional perspectives of Agroforestry. In M. Palo & J. Uusivuori (Eds.), *World Forests, Society and Environment: Markets and Policies* (pp 71-81). Dordrecht, The Netherlands: Kluwer Academic Publishers.

Alavalapati, J.R.R., Shrestha, R.K., & Stainback, G.A. (in press). Agroforestry development: An environmental economic perspective. In P. K. R. Nair, M. R. Rao, & L. E. Buck (Eds.), *New Vistas in Agroforestry*. Dordrecht, The Netherlands: Kluwer Academic Publishers.

Association for Temperate Agroforestry (AFTA). (1997). *The status, opportunities, and needs for agroforestry in the United States*. Columbia, Missouri: AFTA, University of Missouri.

Buongiorno, J., & Gilles, K. (2003). *Decision methods for forest resource management*. San Diego, California: Kluwer Academic Publishers.

Das, G., & Alavalapati, J. R. R. (2003). Trade mediated biotechnology transfer and its effective absorption: An application to the U.S. forestry sector. *Technological Forecasting and Social Change: An International Journal, 70*(6), 545-562.

Garrett, H. E. G. (1997). *Agroforestry: An integrated land-use management system for production and farmland conservation.* [United States Department of Agriculture Soil Conservation Service [USDA-SCS] Report 68-3A7S-3-134]. Fort Collins, CO: USDA-SCS.

Gordon, A. M., & Newman, S. M. (Eds.) (1997). *Temperate Agroforestry Systems*. New York: CAB International.

Mercer, D. E. & Hyde, W. F. (1991). The economics of agroforestry. In W. R. Burch, Jr. & J. K. Parker (Eds.). *Social Science Applications in Asian Agroforestry* (pp. 111-143). New Delhi, India: Oxford & IBH Publishing.

Mercer, D. E., & Miller, R. P. (1998). Socioeconomic research in agroforestry: progress, prospects, priorities. *Agroforestry Systems, 38*, 177-193.

Montambault, J. R., & Alavalapati, J. R. R. (2003). Socioeconomic research in agroforestry: A decade in review. Manuscript submitted for publication.

Nair, P. K. R. (Ed.). (1989). *Agroforestry systems in the tropics*. Dordrecht, The Netherlands: Kluwer Academic Publishers.

Nair, P. K. R. (1994). *Agroforestry. Encyclopedia of agricultural sciences* (Vol. 1, pp. 13-25). New York: Academic Press.

Nair, P. K. R. (1998). Directions in tropical agroforestry research: past, present, and future. *Agroforestry Systems 38*, 223-245.

Rochelau, D. (1998). Confronting complexity, dealing with differences: Social context, content, and practice in agroforestry. In L. E. Buck, J. P. Lassoie, E. C. M. Fernandes (Eds.), *Agroforestry in Sustainable Agricultural Systems* (pp. 191-235). Boca Raton, Florida: CRC Press.

Shrestha, R.K. & Alavalapati, J. R. R. (in press). Valuing environmental benefits of silvopasture practices: A case study of the Lake Okeechobee watershed in Florida. *Ecological Economics*.

STEVEN FRANZEL

FINANCIAL ANALYSIS OF AGROFORESTRY PRACTICES

Fodder shrubs in Kenya, woodlots in Tanzania, and improved fallows in Zambia

1. INTRODUCTION

Over the last two decades, researchers and farmers in east and southern Africa have combined their expertise and knowledge to develop improved agroforestry practices that improve livelihoods and provide important environmental services. Much of the research has focused on increasing biophysical productivity (Sanchez, 1996; Cooper, Leakey, Rao, & Reynolds, 1996), but, during the last 10 years, there has been greater emphasis on social and economic considerations. For example, much work has been done to assess the profitability of these practices and their feasibility and acceptability to farmers (Franzel, Coe, Cooper, Place & Scherr, 2001; Place, Franzel, DeWolf, Rommelse, Kwesiga, Niang et al., 2002).

Analyzing the economics of agroforestry practices is more complicated than that of annual crops for two main reasons. First, agroforestry practices are complex because they involve both trees and crops. Devising field trials to assess agroforestry practices and compare them with other practices is extremely difficult, requiring large plots and, at times, large spaces between the treatments. Second, there is usually a period of several years between the time the trees are established and the impact of agroforestry practices can be measured. Conducting trials and surveys with farmers over several years is expensive and problematic. For example, the greater the length of the trial, the more likely that individual farmers will want to change trial parameters in response to changing circumstances or preferences. The more changes that each farmer makes, the less likely it is that treatments can be compared across farms (Coe, 1998; Franzel et al., 2001).

The objective of this chapter is to assess the financial[1] returns to farmers of three practices: fodder shrubs in Kenya, rotational woodlots in Tanzania, and improved fallows in Zambia. Each practice has a different objective for farmers: fodder shrubs

J. R. R. Alavalapati & D. E. Mercer (Eds.), Valuing Agroforestry Systems, 9–37.

are for increasing milk production, rotational woodlots provide firewood, and improved fallows are for improving soil fertility. In each case, the implications of the analyses for researchers, extensionists, and policy makers are discussed. Finally, conclusions are drawn concerning the attractiveness of agroforestry practices for farmers and research challenges for enhancing their profitability.

2. DESCRIPTION OF THE AGROFORESTRY PRACTICES ANALYZED

2.1. Fodder shrubs, Kenya

The low quality and quantity of feed resources is a major constraint to dairy farming in central Kenya, where farm size averages 1-2 hectares (ha) and about 80% of households have stall-fed dairy cows, averaging 1.7 cows per family. The dairy zone ranges in altitude from 1300 meters (m) – 2000 m and rainfall occurs in two seasons, averaging 1200 millimeters (mm) – 1500 mm annually. Soils, primarily Nitosols, are deep and of moderate to high fertility. The main crops are coffee, produced for cash, and maize and beans, produced for food. Most farmers also grow Napier grass (*Pennisetum purpureum)* for cutting and feeding to their cows. But Napier grass is insufficient in protein so milk yields are low, about 6 kilograms (kg) per cow per day (Murithi, 1998). Commercial dairy meal is available, but farmers consider it expensive and most do not use it (Wambugu, Franzel, Tuwei, & Karanja, 2001; Franzel, Wambugu, & Tuwei, 2003).

Researchers and farmers tested several fodder shrubs around Embu, Kenya in the early 1990s and *Calliandra calothyrsus* emerged as the best performing and most preferred by farmers. The research was led by the National Agroforestry Research Project, a collaborative effort of the Kenya Agricultural Research Institute, the Kenya Forestry Research Institute, and the World Agroforestry Centre. Farmers plant the shrubs in hedges along internal and external boundaries, around the homestead, along the contour for controlling soil erosion, or intercropped with Napier grass. When pruned at a height of 1 m, the shrubs do not compete with adjacent crops. Farmers are easily able to plant 500 shrubs, at a spacing of 50 centimeters (cm), around their farms, and are able to begin pruning them within a year after planting. Five hundred shrubs are required to provide a cow throughout the year with 2 kg dry matter per day, adding about 0.6 kg crude protein. On-farm feeding trials confirmed that the farmers could use the shrubs as a substitute for dairy meal or as a supplement to increase their milk production. Dissemination began in earnest in 1999 and by 2003, about 23,000 farmers had planted *calliandra* or three other recommended species of fodder shrubs (Wambugu et al., 2001; Franzel et al., 2003).

2.2. Rotational woodlots, Tanzania

Tabora Region, western Tanzania, is an area of undulating plains and an average annual rainfall of 880 mm, falling over 5-6 months. Soils are 800-900 g (grams) per kg sand, low in organic carbon, nitrogen, and available phosphorus (Otsyina, Minae, & Cooper, 1996a). Land is a public commodity but farmers have secure user rights to the land they use. Farm size averages about 20 ha, most of which is uncultivated (Otsyina et al., 1996a). Farmers use hand hoes for cultivation. They make extensive use of hired laborers, who migrate to Tabora during the cropping season. Livestock are few, only about 5% of the farmers own cows. (Otsyina, Msangi, Gama, Ramadhani, Nyadzi, & Shirma, 1997). Tobacco is farmers' main cash crop; other crops grown for both food and cash include maize, the main food crop, groundnuts, rice, and sorghum. About 60% of the farmers grow tobacco, averaging 1.0 ha per farm. Firewood for tobacco curing is scarce; most farmers hire trucks and cut and transport firewood themselves from the forest. Farmers do not grow trees traditionally because, until recently, wood was plentiful and because they lack information on tree growing and planting material. Both policy makers and farmers are concerned about the rapid deforestation because an important natural resource is being destroyed and because the cost of collecting firewood is increasing as the distance to sources increases (Ramadhani, Otsyina, & Franzel, 2002).

Research on woodlots in Tabora began in 1993/94 at the Agricultural Research and Training Institute, Tumbi (ARTI-Tumbi). In the rotational woodlot system, farmers intercrop food crops with leguminous trees during the first 2-3 years, to maximize returns to their scarce labor. Then they leave the trees to grow, harvest them in about the fifth year, and replant food crops (Otsyina, Msangi, Gama, Ramadhani, Madulu, & Mapunda, 1996b). The most promising species tested by the farmers, in terms of growth, is *Acacia crassicarpa*, a legume. The food crops grown following the tree harvest benefit from the increase in organic matter, nutrient recycling, and nitrogen fixed by the leguminous trees (Ramadhani et al., 2002). Dissemination began in 1997 and by 2000, 961 farmers had planted woodlots.

2.3. Improved tree fallows, Zambia

The plateau area of eastern Zambia is characterized by a flat to gently rolling landscape and altitudes ranging from 900 to 1200 m. Rainfall averages about 1000 mm per year with about 85% falling in 4 months, December-March. The main soil types are loamy sand or sand Alfisols interspersed with clay and loam Luvisols. About half of the farmers practice ox cultivation, the others cultivate by hand hoe. Average cropped land per farm is 1-1.6 ha for hand hoe cultivators and 2-4 ha for ox cultivators. Maize is the most important crop accounting for 60% of cultivated area; other crops include sunflower, groundnuts, cotton, and tobacco. Surveys in the late 1980s identified soil fertility as the farmers' main problem; fertilizer use had been common during the 1980s but the collapse of the parastatal marketing system and the cessation of subsidies caused fertilizer use to decline by 70% between 1987 and 1995. Farmers had a strong felt need for fertilizer but lacked cash for purchasing it (Peterson, 1999; Franzel, Phiri, & Kwesiga, 2002b).

In 1987, the Zambia/ICRAF Agroforestry Research Project began on-station research on improved fallows, using *Sesbania sesban.* Results were encouraging and on-farm trials began in 1992. By 1995, several hundred farmers were involved in a range of different trials, testing and comparing different options. In researcher-led trials, farmers chose among 3 different species and 2 different management options (intercropping with maize vs. growing the trees in pure stands) and compared their improved fallows with plots of continuously cropped maize with and without fertilizer. In farmer-led trials, farmers planted and managed the improved fallows as they wished. Most farmers opted for a 2-year fallow and planted their main food crop, maize, for 2 to 3 seasons following the fallow. Extension activities began in 1996 and by 2001; over 20,000 farmers in eastern Zambia had planted improved fallows (Kwesiga, Franzel, Mafongoya, Ajayi, Phiri, & Katanga, in press).

3. METHODOLOGY FOR ASSESSING PROFITABILITY

3.1. General methods

Farmers using new agroforestry practices obtain increased financial benefits, relative to their existing practices, either through increased biophysical productivity or through reduced input costs. Both are important in all three of the practices examined in this paper. Researchers assessed biophysical productivity and financial net benefits by comparing results on treatment plots in on-farm trials with those on control plots, which represented farmers' existing practices. In all three cases, the trials were designed by researchers, in consultation with farmers, and they were managed by farmers. Researcher-designed trials are more suitable than farmer-designed ones because plot sizes are standardized, facilitating the collection of labor data, and practices are more uniform, permitting comparisons across farms. Farmer-managed trials are preferred to research-managed ones because data on costs and returns will more accurately reflect what farmers experience. The returns to agroforestry practices are highly sensitive to the timing and quality of certain practices, such as pruning. Thus, farmer management helps ensure that the outcomes of these trials are representative of what farmers can obtain on their own (Franzel et al., 2001).

Financial analyses were based on the costs and returns that farmers faced. The analyses did not use time series data taken from trial farmers because the time between planting and harvesting benefits was too long, 5 years in the case of woodlots and improved fallows. Rather farmers at different stages of a practice were monitored in the same year and composite farm budgets were constructed. Enterprise budgets were used for assessing the financial benefits and costs of improved fallows and woodlots, because these practices involved major changes in the maize enterprises they were being compared to. In enterprise budgets, all costs and returns of an enterprise are assessed. On the other hand, partial budgets were drawn up in the case of fodder trees because the practice had limited impacts on the costs and returns of dairy enterprise. A partial budget is a technique for assessing the benefits and costs of a practice relative to not using the practice. It thus takes into account only those changes in costs and returns that result directly from using a new practice (Upton, 1987).

Detailed information on labor use among participating farm households was collected using two main methods: including farmers' recall just after a task was completed and monitoring of work rates through observation. Prices were collected from farmers and from local markets.

Financial analyses often calculate returns to only one resource, land, ignoring the fact that labor and capital are far greater constraints than land in many farming systems. Therefore, we calculated the net returns to land, which was relevant for farmers whose most scarce resource was land and the net returns to labor, relevant for those who lacked household labor. In calculating returns to land, land was not valued but household labor was valued at its opportunity cost as estimated by hired labor prices. Returns are expressed on a per-hectare basis. For returns to labor, household labor was not valued and returns were expressed per unit of labor, that is, per workday. Net returns to capital for agroforestry practices are often extremely high or infinite because little or no capital is used in implementing them. This finding explained the attractiveness of many of the options because the alternatives, for example, fertilizer to improve crop yields or dairy meal concentrate to increase milk yields, were very expensive for farmers.

Data for a single period are usually inadequate for evaluating the performance of an agroforestry practice. Therefore, cost-benefit analyses, also called investment appraisals (Upton, 1987), were developed for estimating costs and benefits over the lifetime of an investment. Average values for costs and returns across a sample of farmers were used to compute net present values. Also, in the case of improved fallows, net present values were calculated for each individual farm based on its particular costs and returns. This latter method allowed a better understanding of the variation in returns and thus the risk of the practices.

Whereas cost-benefit analyses are useful for determining the net present value of an enterprise that has costs and returns over many years, they do not show the increase in annual income generated. To assess increases in annual income, farm models were developed in which the farm was partitioned, to contain specified portions of land devoted to each phase (corresponding to a season or year) of the practice. For example, in the model of improved fallows in Zambia, the farm was assumed to have equal portions of area in each of the practice's four phases: planting of the improved fallow (year 1), maturing of the fallow (year 2), the first post-fallow maize crop (year 3), and the second post-fallow maize crop (year 4). The net returns of this farm were compared to two other farms having the same amount of labor (the main constraining resource): one planting fertilized maize and the other planting unfertilized maize, both continuously without fallow. The model was thus useful for estimating the impact of improved fallows on annual net farm income and maize production (Franzel et al., 2002b).

3.2. Fodder shrubs

The data on the planting and management of the shrubs are from on-farm trials conducted in the early- and mid- 1990s and are described in Franzel, Arimi, and Murithi (2002a). In these trials, farmers planted and managed the shrubs as they wished; researchers monitored farmers' experiences. The trials could thus be described as farmer-designed and farmer managed. On the other hand, the feeding trials for determining milk yields were researcher-designed and farmer-managed, that is, researchers designed the treatments, in consultation with farmers, and the farmers managed the trials. These trials were conducted in 1994 and 1995 and are described in Patterson, Roothaert, Nyaata, Akyeampong, and Hove (1996).

Partial budgets were drawn up to show the effects of using fodder shrubs on farmers' net income under two scenarios: using *calliandra* 1) as a supplement to the normal diet and 2) as a substitute for purchased dairy meal. The base analysis assumes a farm with 500 trees and 1 zero-grazed dairy cow and covers a 10-year period. In fact the productive life of the tree appears to be longer, farmers who have had their trees for 10-12 years have not yet noticed any reduction in productivity. The benefits included in the analysis are the effect of *calliandra* on milk production (in the supplementation case) and the cash saved by not purchasing dairy meal and interest on cash freed up (in the substitution case). Costs are those for producing the seedlings and labor for planting, cutting, and feeding *calliandra* in 2001. Estimates of these costs were made by interviewing farmers shortly after they had completed the tasks. All costs for producing the seedlings are for labor, except for the cost of hand tools, which are used for other enterprises as well, and for seeds, which are valued at the market rate but which many farmers obtain for free from their own trees, those of neighbors, or from organizations. Therefore, in most cases, no cash expenditures are required for producing fodder shrubs. It is assumed that dairy meal and *calliandra* are fed 365 days per year as is recommended, whether the cow is in lactation or not.

Coefficients, prices, and sources of data used in the economic analysis are shown in Appendix A. Milk output per day per unit of *calliandra* or dairy meal is likely to be higher during the rainy season than during the dry season because there is more available basal feed during the rainy season. As the feeding trials were conducted during the dry season, the milk yields and profits that farmers can get from using *calliandra* or dairy meal may be lower in this study than what farmers can actually get on an average annual basis. The variability of financial returns could not be statistically assessed because a complete set of input-output data was not available for each individual farm. However, sensitivity analysis was conducted to determine the effects of changes in key parameters on profitability.

3.3. Rotational woodlots

For the on-farm trial, tobacco farmers were chosen randomly from 3 tobacco-growing villages in 3 districts, using lists of farmers available at village offices. The selected farmers were then visited to see if they were interested in hosting the on-farm trial. Five farmers planted in 1993/94 (the planting season extends from December to February), 10 in 1994/95, 8 in 1995/96, and 37 in 1996/97. The trial involved three tree species but only the best performing one, *Acacia crassicarpa,* is included in the economic analysis. Seedlings were raised in a nursery and transported to farmers' fields. The trial was researcher-designed and farmer-managed; researchers marked out plots and advised on management but farmers conducted all operations. The trial included 3 plots, 1 for each species, planted at a spacing of 4 m by 4 m (625 trees/ha). Plot size ranged from 0.07 ha to 0.16 ha depending on the land the farmer had available; thus each farmer planted about 44 to 100 trees of each species. Farmers planted maize between the newly planted trees during the first 2 years after the trees were planted. They were also advised to weed, dig micro-catchments around each tree, and apply compound fertilizer, which is recommended for maize. In fact, weeding and applying fertilizer to maize are common practices in the area. Farmers were also trained on how to prune the trees. Wood yield was measured from 4 of the 15 farmers who planted in 1993/94 and 1994/95; only 1 other farmer had harvested their trees. Otsyina et al. (1996b) and Ramadhani et al. (2002) provide more details on the trial.

The profitability of rotational woodlots was assessed by comparing it with a maize-fallow rotation, because farmers planted woodlots on fields that they indicated would have been used for growing maize for 2 years followed by a 3-year fallow. Enterprise budgets for both rotational woodlots and maize-fallow rotations were drawn up over a 5-year period, using data on inputs, outputs, and prices obtained from the farmers and other key informants (Appendix B). The analysis assumes that farmers harvest the woodlots in the fifth year. Wood prices were valued at the price farmers pay to have wood trucked in from the forest for curing their tobacco. Labor inputs and wage rates were obtained from a formal survey of 30 trial farmers in 1997. Maize seed and harvest prices were averages of market prices over the period 1995/96-1996/97. Maize yields with and without trees were not measured, but the trees were estimated to have no effects on maize yields in the first year and to reduce maize yields by 40% in the second year, based on results from an on-station trial and observations (Otsyina et al., 1996b).

A farm-level model was drawn up to assess the impact of rotational woodlots on farm profitability. In the first scenario of the model, the farmer uses 75 workdays year^{-1} to grow 1.33 ha of rotational woodlots, planting one-fifth of this amount, 0.27 ha, each year, the area needed to provide sufficient firewood each year for domestic use and for curing 1 hectare of tobacco. In the second scenario, the farmer uses the same amount of labor to cultivate maize. As in the case of fodder trees, sensitivity analysis was used to assess how changes in key parameters affected profitability.

3.4. Improved fallows

During 1996-98, data were collected on costs and returns from 12 selected farmers planting *sesbania* improved fallows in researcher-designed, farmer-managed trials.

All trials included an improved fallow plot and plots continuously cropped with and without fertilizer. Data from these trials were supplemented by data from other farmers, local markets, and secondary sources. The 12 were the only ones who had complete sets of yield response data from the improved fallow trials during 1995/96 and 1996/97. Enterprise costs and returns were drawn up for the 12 farms and used to calculate net present values per hectare to assess returns to land and net returns to labor. The analysis covered a period of 5 years: 2 years of fallow and the 3 subsequent years for which it is assumed that maize yields would be affected. Maize yields following *sesbania* fallows were available for 5 farmers for 1996 and 7 farmers for 1997. Average data on costs were used in each individual farmer's budget; maize yields from different treatments were measured on each farm and were thus specific to each farm. Where costs were a function of yield, as in the case of harvesting labor, they were adjusted in relation to yield. Sensitivity analysis was conducted to show the effects of changes in parameters on the results of the economic analysis.

Farm models were drawn up to assess the impact of adopting improved fallows on annual income, as mentioned above. Models were drawn up for the same three scenarios as for the enterprise budgets: farms that adopt improved fallows (planting a portion of their maize area to improved fallows each year, so that each portion is in a different phase of improved fallows), farms that cultivate unfertilized maize, and those with fertilized maize.

4. RESULTS AND DISCUSSION

4.1. Fodder shrubs

Partial budgets for *calliandra* as a supplement to farmers' basal feed and as a substitute for dairy meal in 2001 are shown in Tables 1-2. Tree establishment costs (including the costs of producing bare-rooted seedlings[2] in a nursery and transplanting them) are modest, $US 7.14/500 trees. Beginning in the second year, harvesting and feeding 2 kg dry *calliandra* per day as a supplement throughout the lactation period increases milk production by about 372 kg[3]/yr., an increase of about 12% over base milk yields. Incremental benefits per year after the first year are over 9 times higher than incremental costs. The net present value (NPV) assuming a 20% discount rate is $US 260. Net benefits per year after year 1 are $US 79.

In the partial budget assessing *calliandra* as a substitute for dairy meal, establishment, cutting, and feeding costs are the same as in the preceding analysis. By feeding *calliandra*, the farmer saves the money he would have spent buying and transporting 730 kg dairy meal during the year. Incremental benefits per year after the first year are over 13 times higher than incremental costs. Milk production does not increase but net benefits are slightly higher than in the supplementation case. The NPV assuming a 20% discount rate is $US 413. The net benefits per cow per year after year 1 are $US 125. Therefore, using *calliandra* increases farmers' annual income by about $US 79 to $US 125 per cow per year after the first year, depending

Table 1. Partial budget: Extra costs and benefits of using calliandra as a supplement for increasing milk production, central Kenya ($US/yr, 2001).

Year	Extra cost		Extra benefit		Net benefit
	Item	*$US*	*Item*	*$US*	*$US*
1	Tree seedlings	3.85			
	Planting labor	3.3			
	Subtotal	7.14		0	-7.14
2	Cutting/feeding labor	10.03	Extra milk produced (372 kg)	89.18	79.16

Net Benefit = extra benefits minus extra costs. Years 3-10 same as year 2. Net present value at 20% discount rate = $US 259.95 per year; Net benefit per year after year 1 = $US 79.16; Annualized net benefit treating establishment costs as depreciation = $US 76.77. Note: Base farm model: The farm has 500 calliandra trees and one dairy cow. The cow consumes a basal diet of 80 kg Napier grass per day and produces 10 kg milk/day. Coefficients are from Appendix A.

Table 2. Partial budget: Extra costs and benefits of using calliandra as a substitute for dairy meal in milk production, central Kenya ($US/yr, 2001)

Year	Extra cost		Extra benefits		Net benefit
	Item	*$US*	*Item*	*$US*	*$US*
1	Tree seedlings	3.85		0	
	Planting labor	3.3			
	Subtotal	7.14			-7.14
2	Cutting; feeding labor	10.03	Saved dairy meal cost	129.72	
			Saved dairy meal transport	4.02	
			Interest on capital	1.11	
	Subtotal	10.03		134.85	124.82

Years 3-10 same as year 2. Net present value at 20% discount rate = $US 413.36. Net benefit per year after year 1 = $US 124.82. Annualized net benefit treating establishment costs as depreciation = $US 122.44. Note: Base farm model: Same as in Table 1. Coefficients are from Appendix A.

on whether the farmer is supplementing or substituting. As the average farmer owns 1.7 cows, *calliandra* has the potential to increase a farmers' income by about $US 134 to $US 212 per year representing an increase of roughly 10% in total household income (Murithi, 1998).

The net benefits per cow per year after the first year are somewhat lower than those calculated for the years 1996-1998, as reported in Franzel et al. (2002a). Net benefits for 1996-1998 (expressed in 2001 dollars after adjusting for inflation) ranged from $US 114 to 183 per cow per year after the first year, depending on whether *calliandra* was used for supplementation or substitution. The 2001 figures, $US 79 to $US 125, represent a reduction of about 30% as compared to the 1996-98 figures. The main causes of the decline were an adjustment in the input-output coefficient (the amount of milk produced from *calliandra*) and a reduction in milk prices, associated with a decline in processing facilities following the collapse of Kenya's dairy marketing parastatal in the late 1990s.

The analyses confirm that the costs of establishing, maintaining, and feeding *calliandra* are low. In both the substitute and supplement scenarios, farmers recover their costs very quickly, in the second year after planting. In order to break even, a farmer using *calliandra* as a supplement needs to obtain only 0.08 kg of milk from 1.0 kg of *calliandra* (dry), rather than the 0.62 kg milk per kg (dry) of *calliandra* obtained in on-farm trials and assumed in the analysis (Paterson et al., 1996).

Several intangible or otherwise difficult to measure benefits and costs have been omitted from this analysis. *Calliandra* provides benefits to some farmers as firewood, in erosion control, as a boundary marker, a fence, and as an ornamental. It also increases the butterfat content of milk, giving it a richer taste and creamier texture. When used as a supplement, *calliandra* may improve animal health and fertility and reduce the calving interval. Finally, several farmers noted that *calliandra* had important benefits relative to dairy meal: it was available on the farm, cash was not needed to obtain it, and its nutritional content was more reliable than that of dairy meal. These views support the thesis that farmers prefer enterprises and practices that do not rely on uncertain governmental or market mechanisms (Haugerud, 1984). The main cost not assessed was the opportunity cost of the land occupied by the shrubs. However, this cost is likely to be low or none, especially when *calliandra* replaces or is added to an existing hedge or bund, is planted on contour bunds to conserve soil, or when *calliandra* hedges border on homesteads, roads, paths, or field boundaries. Another possible cost is the effect on nearby crops. But, because the shrubs are nitrogen fixing and are usually maintained at heights of only 1 m, they have little or no negative effects on adjacent crops. In a survey of *calliandra* growers, only 7% felt that the shrubs reduced the yields of nearby crops (Franzel et al., 2002a).

Sensitivity analysis was conducted to determine how changes in key parameters would affect the results (Table 3). A 30% reduction in the milk price would reduce the NPV by 35%. However, using *calliandra* would still be profitable. In the substitute scenario, changing the milk price would not affect the profitability of *calliandra* relative to dairy meal. A change in the price of dairy meal does not affect the use of *calliandra* as a supplement. However, in the substitution scenario, a 30% increase in dairy meal price raises the NPV by 32%. A reduction of price by 30% reduces the NPV by 32%. Overall, the sensitivity analysis shows that the net benefits of using *calliandra* as a supplement or as a substitute are very stable. Despite the range of negative situations tested, net present values and net benefits remain positive.

Table 3. Sensitivity analysis showing the effect of changes in key parameters on the profitability of using calliandra, central Kenya ($US per cow per year).

	Dairy meal supplement		*Dairy meal substitute*	
	Net present	*Annualized*	*Net present*	*Annualized*
Base Analysis	260	77	413	122
Milk price + 30%	350	103	413	122
Milk price –30%	170	50	413	122
Dairy meal + 30%	260	77	545	162
Dairy meal – 30%	260	77	281	83
Discount rate = 10%	408	77	644	122
Discount rate = 30%	178	76	286	122
Using potted seedlings	250	73	404	119
1 kg shrubs give 30% more milk	350	103	413	122
1 kg shrubs give 30% less milk	170	50	413	122
Labor cost + 30%	249	73	402	119
Labor cost – 30%	271	80	425	126

Note: Base analyses are shown in tables 1 and 2.

Fodder trees appear to be appropriate for smallholder dairy farmers throughout the highlands of eastern Africa – *calliandra*, for example, can grow at altitudes between 0 and 2200 m, requires only 1,000 mm rainfall, can withstand dry seasons up to four months long, and is suitable for cut-and-carry feeding systems or for grazing systems (Roothaert, Karanja, Kariuki, Paterson, Tuwei, Kiruiro et al., 1998). It is also suitable for dairy goat production, which is growing rapidly in Kenya. The potential impact of fodder trees thus appears to be very large. If all 625,000 smallholder dairy farmers were to adopt *calliandra* or similar fodder shrub species, the benefits would amount to about US $ 84 million per year. Moreover, fodder trees are being planted by dairy farmers at numerous other sites in east and southern Africa. Over 10,000 farmers have adopted fodder trees in Uganda and Tanzania; farmers are also planting them in Rwanda, Ethiopia, Malawi, and Zambia.

4.2. Rotational woodlots

Additional costs involved in rotational woodlots, relative to the maize-fallow system, included costs associated with producing tree seedlings, reduced maize yields, and labor for transplanting, gapping, pruning, and wood harvesting (Table 4). In the woodlot treatments, maize costs and yields are lower in the second year than in the first year because maize is planted at a lower density, less fertilizer is used, and because the trees interfere with the maize. In the maize fallow system, maize costs and yields were only measured during the first year of the cultivation; values in the second year are assumed to be the same as in the first year. Labor use in the woodlots system over the 5-year period is over 2.5 times that of the maize fallow system, primarily because of the labor required for wood harvesting in year 5, which accounts for over half of total labor. The total discounted input costs of rotational woodlots were 52% higher than for the maize-fallow system, mainly because of the costs of producing the potted seedlings and of harvesting the trees.

In the first year, the rotational woodlot incurred losses of $US 37 while the maize-fallow system's net benefits were $US 40. Additional benefits of the woodlots included the value of pruned wood in year 2 and wood yields in year 5. The payoff period for the woodlot, that is, the period required to earn positive net benefits, is 5 years as compared to less than 1 year for the maize-fallow system.

Table 4. Financial analysis of rotational woodlot as compared to a maize allow system, Tabora District, Tanzania ($US/ha). [a]

	Rational woodlots[b]			*Maize fallow system*[c]	
Benefits and costs	*Year 1*	*Year 2*	*Year 5*	*Year 1*	*Year 2*
Benefits					
Maize grain yield	142.54	88.85		158.39	158.39
Wood yield			806.62		
Pruning yield		23.53			
Total benefits	142.54	112.38	806.62	158.39	158.39
Labor costs					
Land preparation	8.59	8.59		8.59	8.59
Planting	2.53	1.9		2.53	2.53
Weeding	9.41	9.41		9.41	9.41
Fertilizer application	1.18	1.18		1.18	1.18
Harvesting	7.12	6.05		7.12	7.12
Threshing	3.71	2.33		4.12	4.12
Transplanting, watering, and digging microcatchments	4.18				
Gapping	1.42				
Pruning		5.18			
Wood harvesting			93.14		
Total	38.13	34.64	93.14	32.94	32.94
Other costs					
Tree seedlings	56.3				
Maize seed	4.62	3.7		4.62	4.62
Fertilizer	80.67	64.54		80.67	80.67
Total	141.6	68.24		85.29	85.29
Summary data					
Grand total cost	179.72	102.87	93.14	118.24	118.24
Discounted costs	275.11			180.64	

(Table 4, cont.)

	Rational woodlots[b]			*Maize fallow system*[c]	
Benefits and costs	*Year 1*	*Year 2*	*Year 5*	*Year 1*	*Year 2*
Net benefit	-37.17	9.51	713.48	40.16	40.16
Workdays	0.11	0.1	0.27	0.09	0.09
Net benefit to labor	0.96	44.14	806.62	73.1	73.1
Net ben. to labor/workday	0.02	0.75	5.09	1.31	1.31
Net present value	388.52			61.36	
Discounted workdays	0.31			0.14	
Discounted net benefit to labor	498.25			111.68	
Discounted net benefit and workday	2.67			1.31	

[a]Prices and quantities of inputs and outputs are from Appendix B.
[b]Maize is intercropped with the trees during the first two years. There are no benefits or costs during years 3 and 4. All costs and benefits are discounted over a 5 year period.
[c] Maize is cultivated for two years followed by three years of fallow. There are no benefits or costs during years 3 through 5. All costs and benefits are discounted over a 5 year period.

In spite of its higher costs and longer payoff period, the rotational woodlot's net present value is $US 388/ha, over 6 times higher than that of the maize fallow system. Returns to labor are more relevant to Tabora farmers than returns to land, because labor is much scarcer than land. The woodlot's returns to labor, expressed in discounted net benefits per discounted workday, were $US 2.67, over double that of the maize-fallow system.

An important advantage of the woodlots is that they allow farmers to substitute land and labor for cash, which they have great difficulty obtaining. Tobacco farmers can obtain firewood for curing only by purchasing it, whereas with the rotational woodlots, they can use their land and labor to produce it, using little if any cash in the process. The labor required for harvesting the wood is considerable but it can be spread over a long period during the farmers' slack season. The extra labor required for planting and maintaining the trees is relatively little.

Sensitivity analysis showed that the performance of rotational woodlots relative to the maize-fallow system is fairly stable across a wide range of changes in important parameters (Table 5). Increases or decreases of 50% in the price of maize, wood, or labor, or in the yields of maize or wood do not affect the superiority of rotational woodlots. Increasing the discount rate from 20% to 30% or reducing it to 10% also does not affect the rankings. Among the variables examined, the profitability of the woodlots is most sensitive to changes in the wood price and yield. The profitability of the maize-fallow system is sensitive to changes in maize price and yield.

The farm model (Table 6) shows that a household with 1.33 ha under woodlot, planting and harvesting 0.265 ha each year, would be able to provide enough wood to meet its tobacco curing and domestic needs each year. Such a household would use 75 workdays and earn $US 182, over triple the net returns that a family would earn using the same amount of labor to produce maize.